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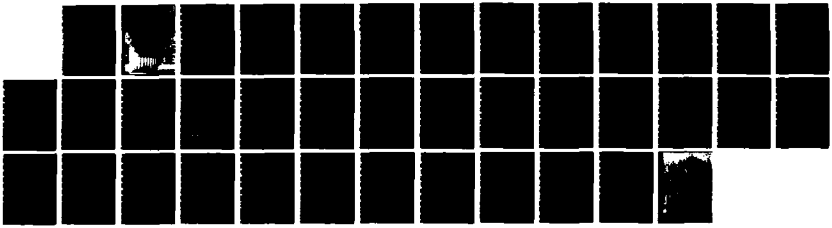

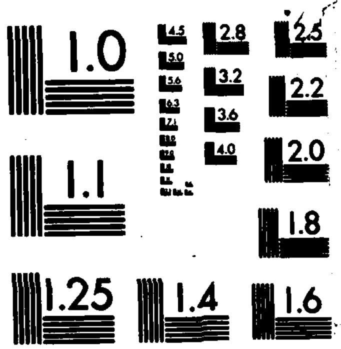

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MEASUREMENTS OF THE LOW WAVENUMBER WALL PRESSURE SPECTRAL DENSITY DURING TRANSITION ON A FLAT PLATE

by

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and

PATRICK LEEHEY

Report No. 93019-1

April 1984

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Experimental measurements of the low-Mach number wall pressure spectra density in the transition region are currently carried out in our laboratory. The six element (B&K Model #4144) microphone array used by Farabee and Geib was used as the wavenumber filtering apparatus and flush mounted on an open test section identical to that used by Jameson.

A technique of conditional sampling on signals was used to determine the characteristics of the transitional flow. The frequency spectrum of

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the microphone array output was computed for uniform shading, Chebyshev shading and binomial shading. A detailed update on our progress is enclosed.

The preliminary results indicate that there is no significant measurable difference in the low wavenumber wall pressure spectrum density for a transitional boundary layer as compared to a fully turbulent boundary layer.

Measurements of the Low Wavenumber Wall Pressure Spectral Density During Transition on a Flat Plate

I. INTRODUCTION

Experimental measurements of the low wavenumber wall pressure spectral density are currently underway in the transition region of a flat plate boundary layer. A brief description of the experiments and of some preliminary results will be given here.

It is well known that the low wavenumber region of the wall pressure spectral density (hereafter referred to as just the low wavenumber region) is much more efficient at exciting marine structures than the convective region. Considerable effort has therefore been directed into the measurement of the spectrum levels in this region, while rejecting the contributions from the convective region.[1-4] The transition region of a boundary layer may cover a large portion of some structures and thus it is imperative that the low wavenumber region be well understood for a boundary layer undergoing transition.

II. EXPERIMENTAL DESCRIPTION

The low-noise, low-turbulence wind tunnel facility of the MIT Acoustics and Vibration Laboratory is being used to conduct the experiments. This facility has been used in the past to study the low wavenumber region,[5,6] and the transition process.[7-8] Its characteristics are described in our previous progress report (dated 6 October 1983) as well as in Hanson.[10] The test setup used in the experiments is shown in Figure 1. This figure shows that the measurements were made using an open test section as in Jameson.[4] As opposed to a closed configuration, the open test section does not act as an acoustic wave guide and the resulting acoustic noise levels are lower. Figure 1 also indicates the approximate locations of the laminar, transition and turbulent regions of the boundary layer as well as the position of the microphone array.

The six element (B&K Model #4144) microphone array used by Farabee & Geib[3] was used as the wavenumber filtering apparatus. Figure 2 is a schematic of the instrumentation used in our work. The frequency response of the array was flat from 3Hz to about 8kHz. The microphones' sensing areas have 0.89cm radii (R), with a center-to-center spacing (in the streamwise direction) of 2.69cm (d). The microphones were flush mounted into the test section and their signals were high pass filtered at 100Hz. The individual microphone gains were adjusted with a Precision Filters Model 32C02B Preamp/Filter set so that various shadings could be used. The microphone outputs were then summed together with alternating phases. That is, the phase of every other microphone signal was inverted prior to the summation. The frequency spectrum of this summed signal (the array output) was then computed with a Hewlett-Packard Model 5324A Structural Dynamics Analyzer. The signal from the third microphone (counting from the upstream microphone) was also analyzed with the 5324A. The wavenumber response of the array (with alternating phases and uniform shading) is shown in Figure 3.

III. RESULTS

The preliminary experimental results will be presented in two parts. First, the boundary layer parameters will be presented followed by results of the wall pressure measurements.

In the transition region, the bulk of the wall pressure fluctuations at a given point are due to the passage of turbulent spots. Therefore, the boundary layer parameters of interest are those characteristic of the spots themselves and are not merely the time averaged properties.

Boundary Layer Characteristics

The intermittency factor (γ) at a point in a boundary layer is defined as the fraction of time that the boundary layer exhibits a turbulent nature at that point. It has been shown[11] that the mean boundary layer properties in the intermittent region are weighted averages of the corresponding mean laminar and mean turbulent properties, where γ is the weighting factor. Therefore, the velocity profiles of the turbulent part of the boundary layer were computed from the measured mean intermittent profiles, the intermittency factors and the known laminar profiles. The intermittency factors for several flow conditions were computed for the third microphone signal using the numerical techniques described by Gedney.[8] These values for γ were considered to be representative of the intermittency factors for the entire array. The mean boundary layer profiles at these conditions were measured with a small total head tube which was traversed across the boundary layer. Figures 4 and 5 show the measured velocity profiles for two flow conditions compared to laminar and turbulent profiles. These figures show that the measured velocity is indeed a weighted average of the velocities for the laminar and turbulent parts. Figures 6 and 7 show the velocity profiles for the turbulent part of the flow, computed from the measurements of Figures 4 and 5 along with the law of the wake model proposed by Coles.[12] The agreement between the measured profiles and the law of the wake is very good, indicating that the boundary layer in the open test section was not adversely affected by the open jet. Table 1 lists the boundary layer parameters (for the turbulent portion of the flow) at the eight flow conditions. These parameters were used in the nondimensionalization of the wall pressure measurements. Flow speeds of 11, 14, 19 and 24m/s were selected at two roughness conditions. The roughness conditions were 1) a smooth wall and 2) a 0.02" diameter trip wire was stretched spanwise across the plate at the open jet exit plane (see Figure 1). In Table 1 U_∞ is the freestream velocity, δ^* is the displacement thickness and V_* is the friction velocity.

Wall Pressure Measurements

The frequency spectrum of the microphone array output was computed for each of three shadings at all eight of the flow conditions of Table 1. This gave a total of 24 frequency spectra.

TABLE 1

Run #	U_∞(m/s)	Roughness Condition	γ	δ^*(mm)	V_*(m/s)
1	11	smooth	0.38	2.03	--
2	14	"	0.66	1.24	0.68
3	19	"	0.86	1.40	0.91
4	24	"	1.0	1.45	1.1
5	11	trip wire	0.63	1.52	--
6	14	"	1.0	1.35	0.68
7	19	"	1.0	1.42	0.88
8	24	"	1.0	1.73	1.0

NOTE: V_* was not computed for Run #1 and #5 due to experimental errors.

The three shadings were: 1) uniform shading; 2) Chebyshev shading [with lower side lobes and a wider main lobe than the uniform shading, see Figure 3]; and 3) binomial shading [with even lower side lobes and a wider main lobe than the Chebyshev shading]. A typical frequency spectrum of the array output is shown in Figure 8. The frequency spectrum of microphone #3 at the same conditions is also shown in the figure. The single microphone results of Figure 8 show a low frequency peak near 200Hz due to the convective ridge. The decay of this convective response with increasing frequency is due to spatial averaging on the diaphram of the microphone. The relatively flat portion of the single microphone results above 3kHz is due to acoustic noise in the flow. The frequency spectrum of the array output in Figure 8 shows reductions in the magnitude of the measured pressure at various frequencies due to the wavenumber filtering characteristics of the microphone array. The first three peaks in this spectrum (at about 200, 600 and 1400Hz) are due to the array responding to the convective ridge in the main, first aliasing and second aliasing lobes. The broad peak at 5.6kHz is the response of the array in its main lobe to the acoustic noise. Likewise, the peak at 3.2kHz is due to the array's first lower side lobe responding to the acoustic noise (this spectrum was measured with uniform shading). The measurements of the low wavenumber region were taken from this curve at the frequency points above the peak at 1400Hz, where the response of the array to the acoustic noise was a minimum. In this way the low wavenumber results have the least amount of contamination from either the convective ridge or the acoustic noise for each test condition. The array's acoustic response minima were determined from plots of the coherence between the single microphone signal and the array output.

The coherence is defined by

$$C(\omega) = \frac{|S_{MA}(\omega)|^2}{S_{MM}(\omega)S_{AA}(\omega)}$$

where $C(\omega)$ is the coherence, $S_{MA}(\omega)$ is the complex cross spectral density between the single microphone and the array, and $S_{MM}(\omega)$ and $S_{AA}(\omega)$ are the power spectral densities of these two signals. Figure 9 is a plot of the coherence function for the conditions of Figure 8. The minima at 2.4 and 4.2kHz in Figure 9 indicate the frequency points at which the array had the smallest response to the acoustic noise and these frequencies are where the low wavenumber results were taken. The fact that the minima in Figure 9 nearly go to zero indicates that the bulk of the acoustic noise is propagating in the stream direction

The main lobe of the microphone array was centered on wavenumbers of 1.17cm^{-1} in the streamwise direction and 0 in the spanwise direction. The array's wavenumber response ($|W(\underline{k})|^2$) and effective wavenumber bandwidths (Δk_1, streamwise and Δk_3, spanwise) were computed for uniform shading from the following relation given by Farabee and Geib:[3]

$$|W(\underline{k})|^2 \Delta k_1 \Delta k_3 = 5.7(4/N)\text{cm}^{-2}$$
$$= 3.82\text{cm}^{-2}, \quad \text{with } N=6 .$$

The increases in the streamwise bandwidths due to the Chebyshev and binomial shadings were 53% and 100% respectively. It was assumed that the magnitude of the wall pressure spectral density was constant with wavenumber over the array's main lobe and a single value for the spectral density was computed.

Figure 10 is a plot of the wall pressure spectral density in the low wavenumber region plotted in a nondimensional form versus a nondimensional frequency. In this plot, q is the dynamic head, γ is the intermittency, δ^* is the displacement thickness and U_∞ is the free stream velocity. The data in Figure 10 were measured at various intermittencies ranging from 0.38 to 1.0 and are compared to results measured in fully turbulent boundary layers by Martin[5] and Jameson.[4] Both Martin and Jameson used the spatial filtering characteristics of vibrating plates to make their measurements in the low wavenumber region.

The preliminary results of Figure 10 indicate that there is no significant measurable difference in the low wavenumber wall pressure spectral density for a transitional boundary layer as compared to a fully turbulent boundary layer (at least when compared to the levels reported by Martin).

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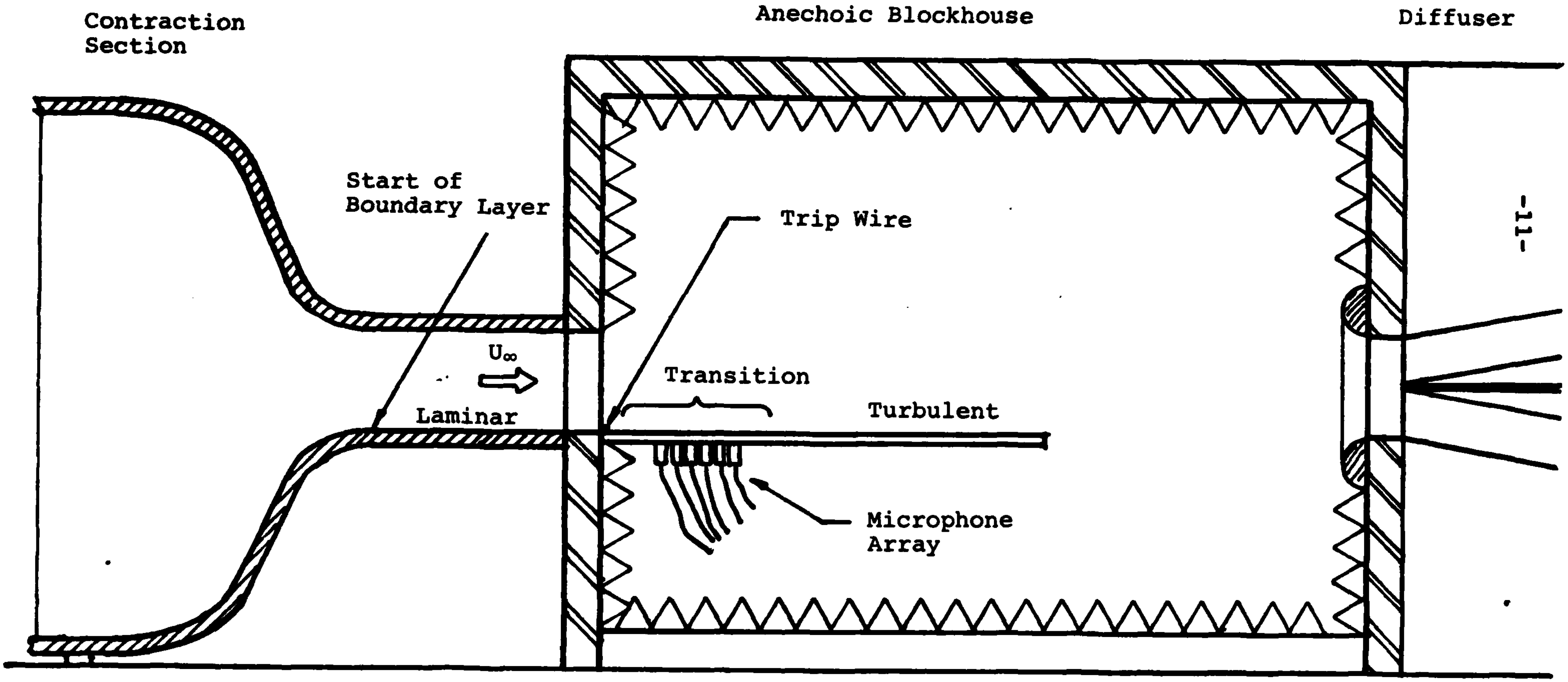

Figure 1. Side View of Wind Tunnel in Cross Section.

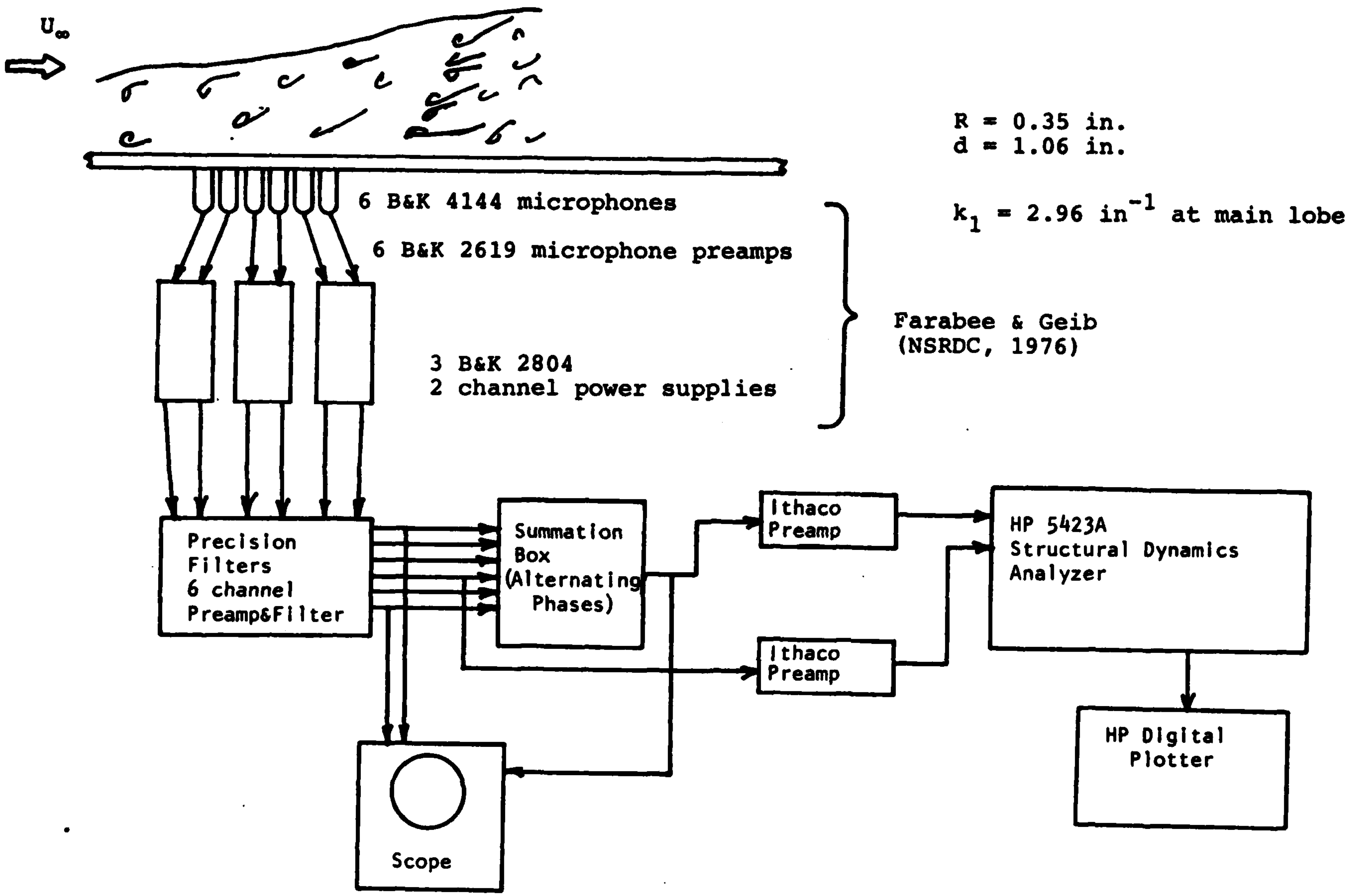

Figure 2. Instrumentation.

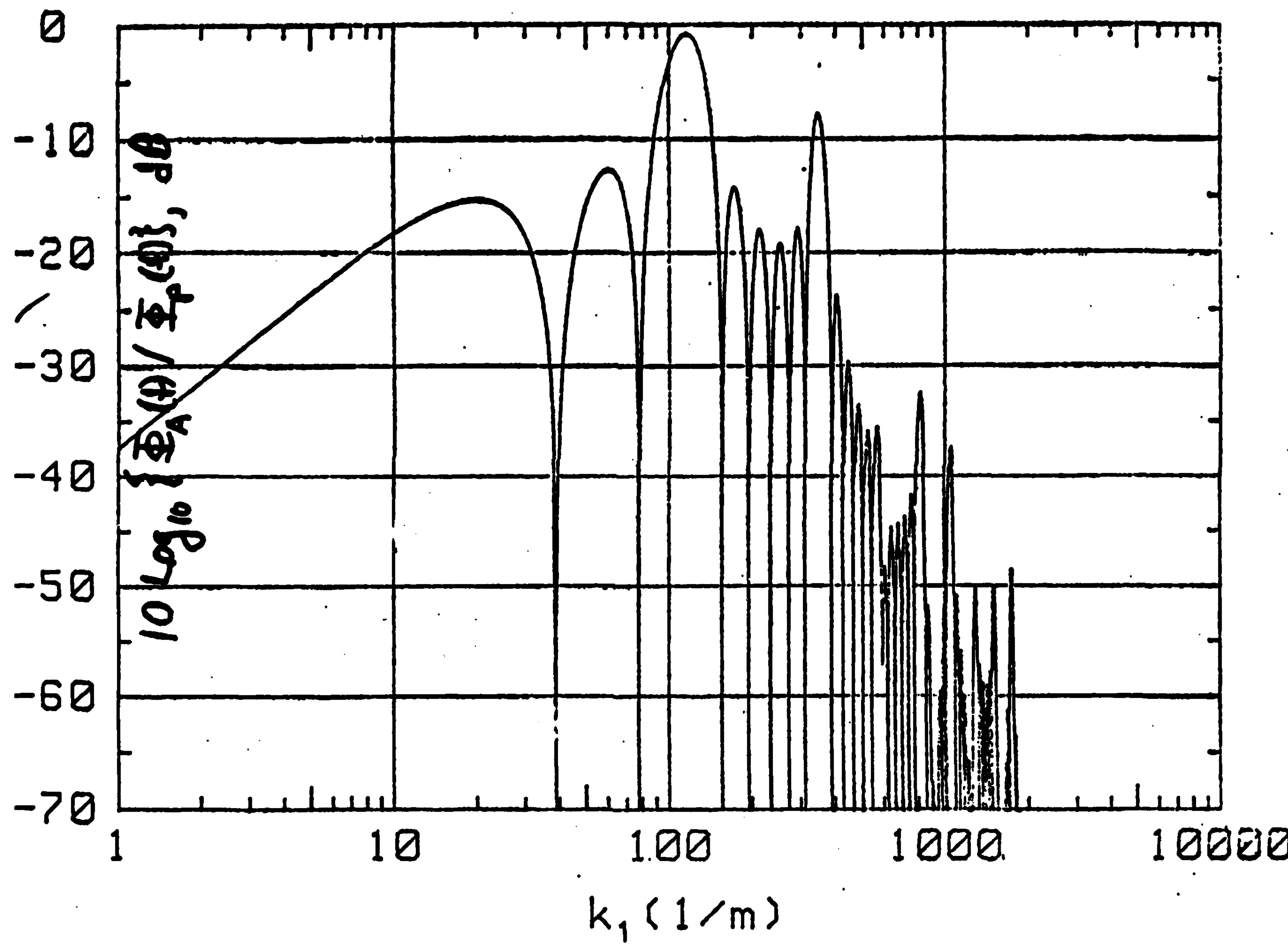

Figure 3. Calculated Wavenumber Response, Alternating Phased Array.

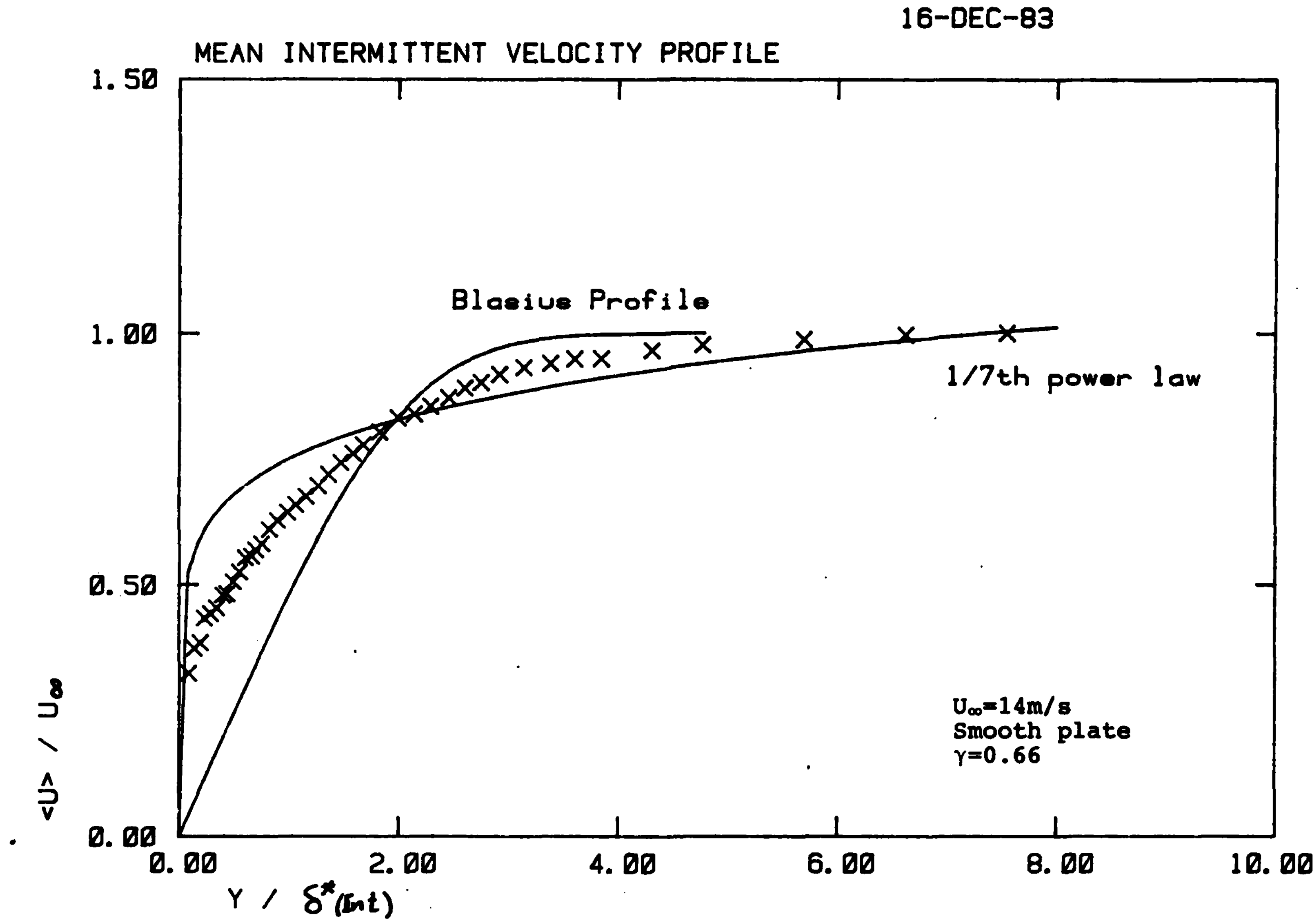

Figure 4. Typical Mean Boundary Layer Profile.

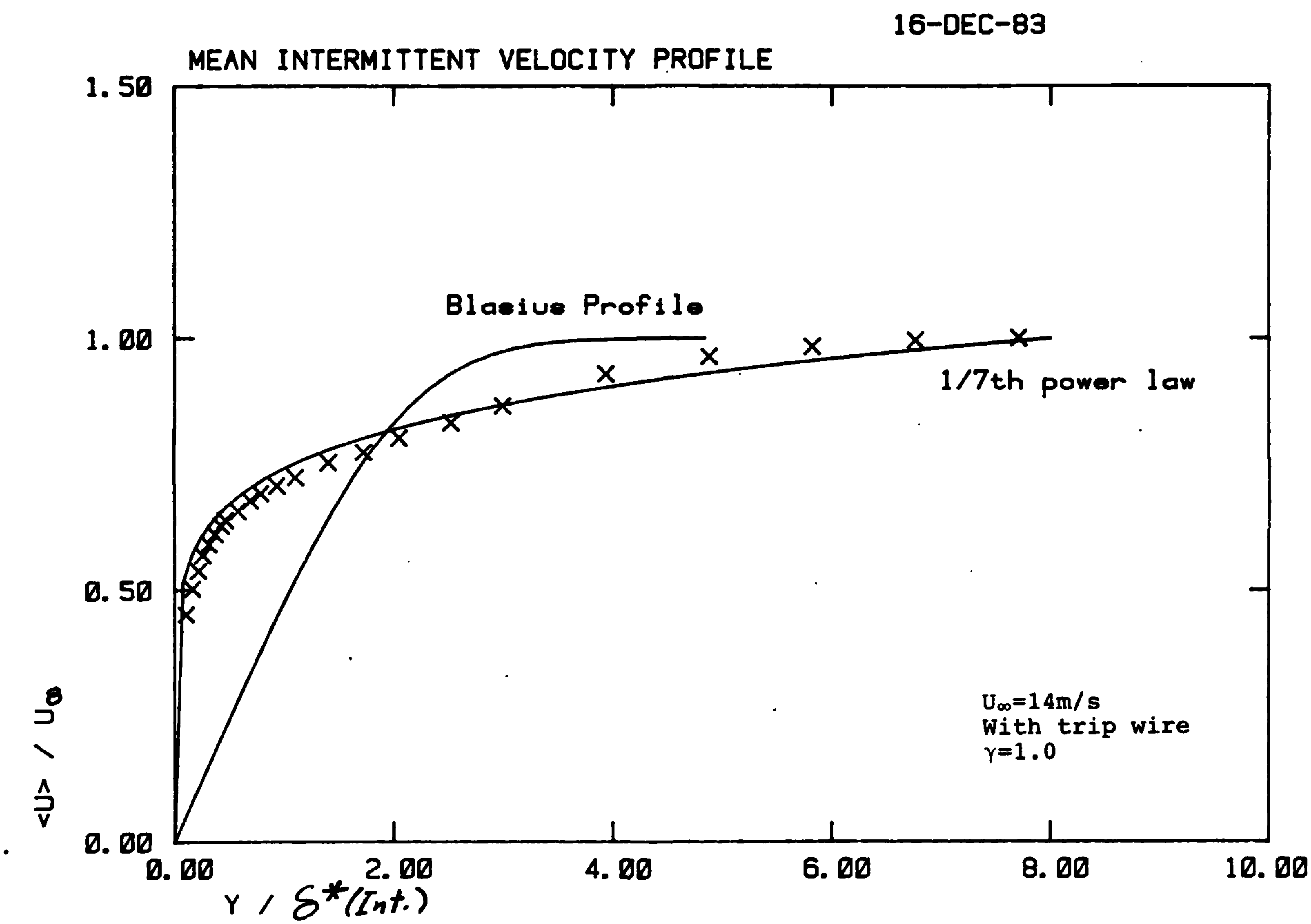

Figure 5. Typical Mean Boundary Layer Profile.

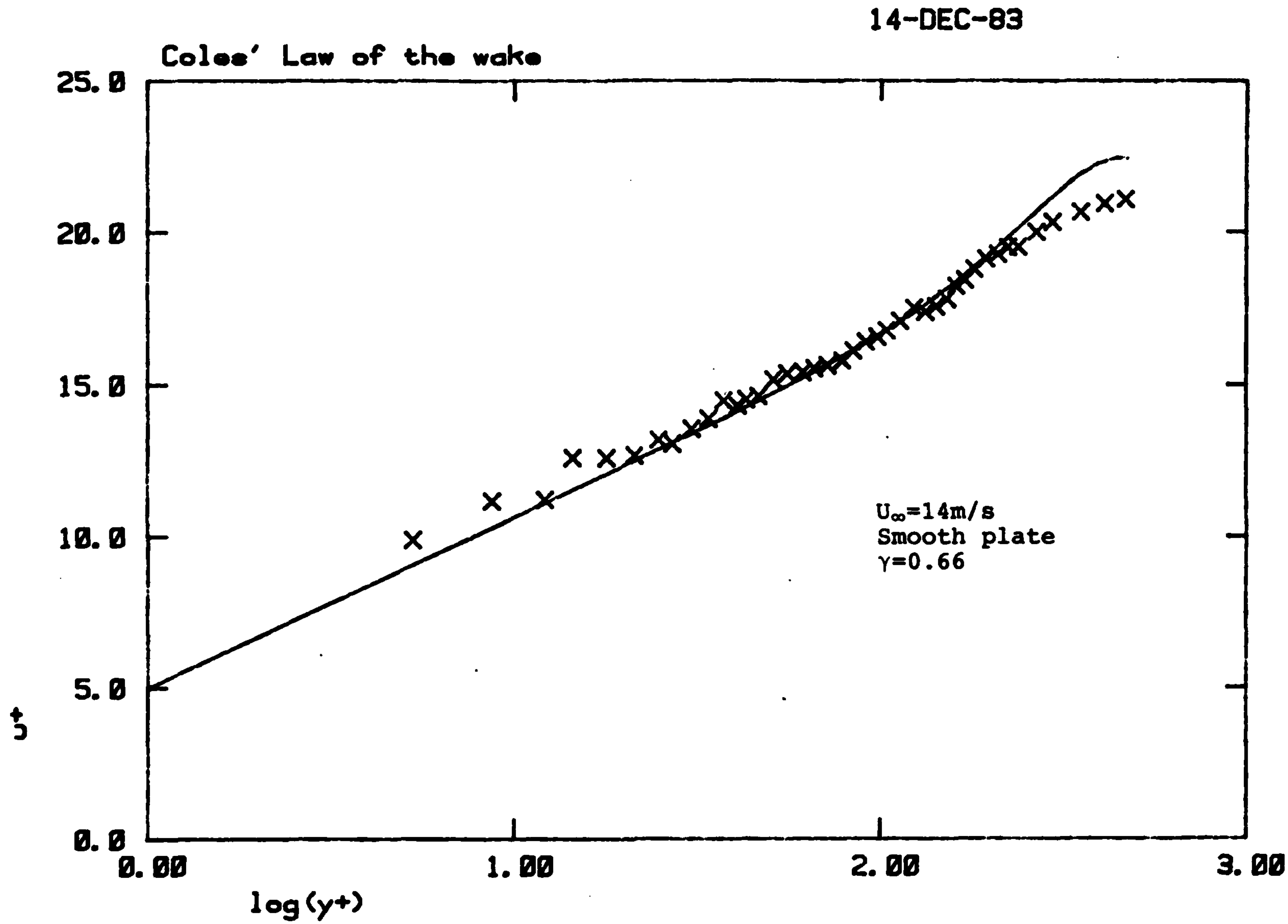

Figure 6. Turbulent Boundary Layer Profile.

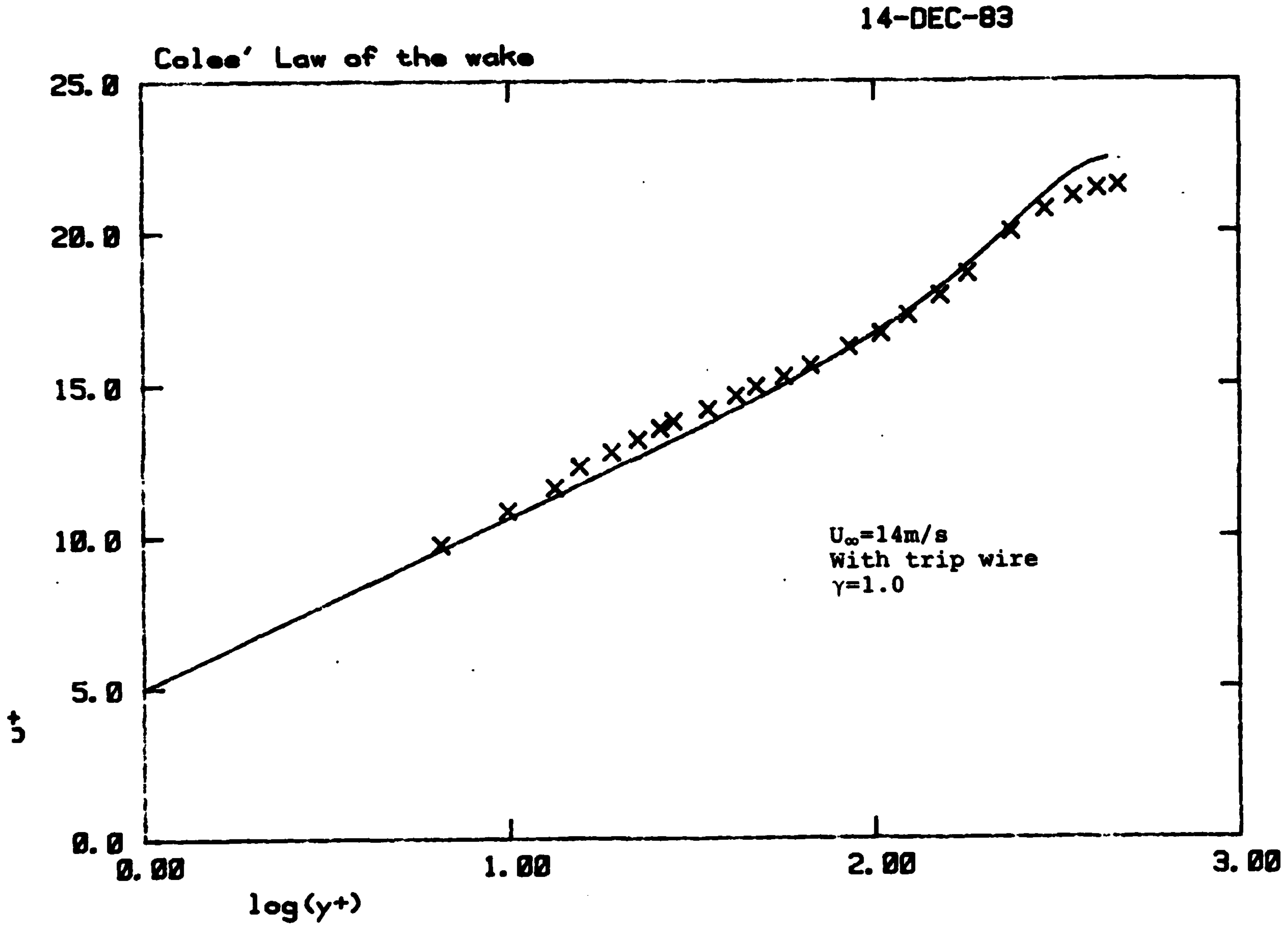

Figure 7. Turbulent Boundary Layer Profile.

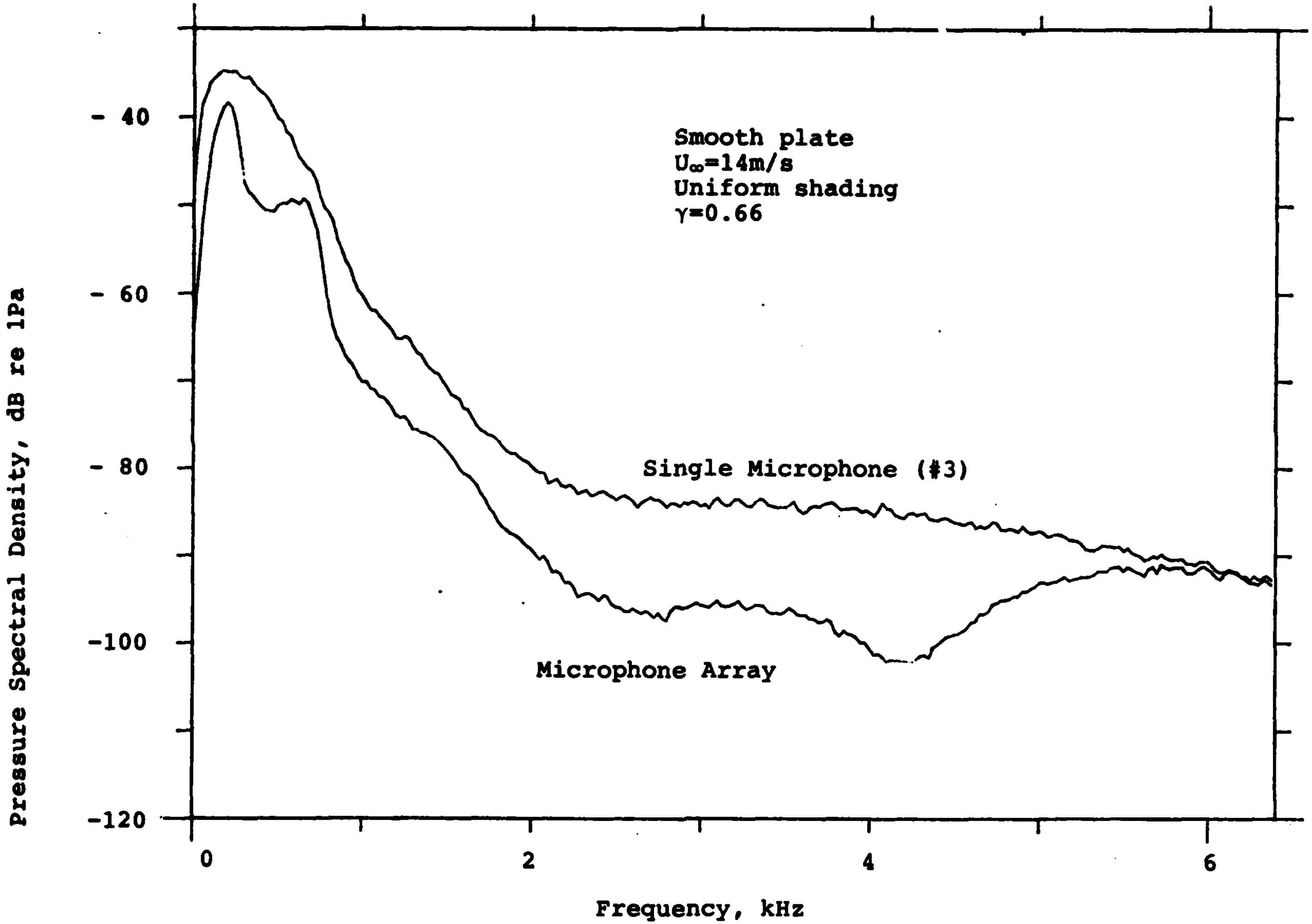

Figure 8. Typical Wall Pressure Frequency Spectra.

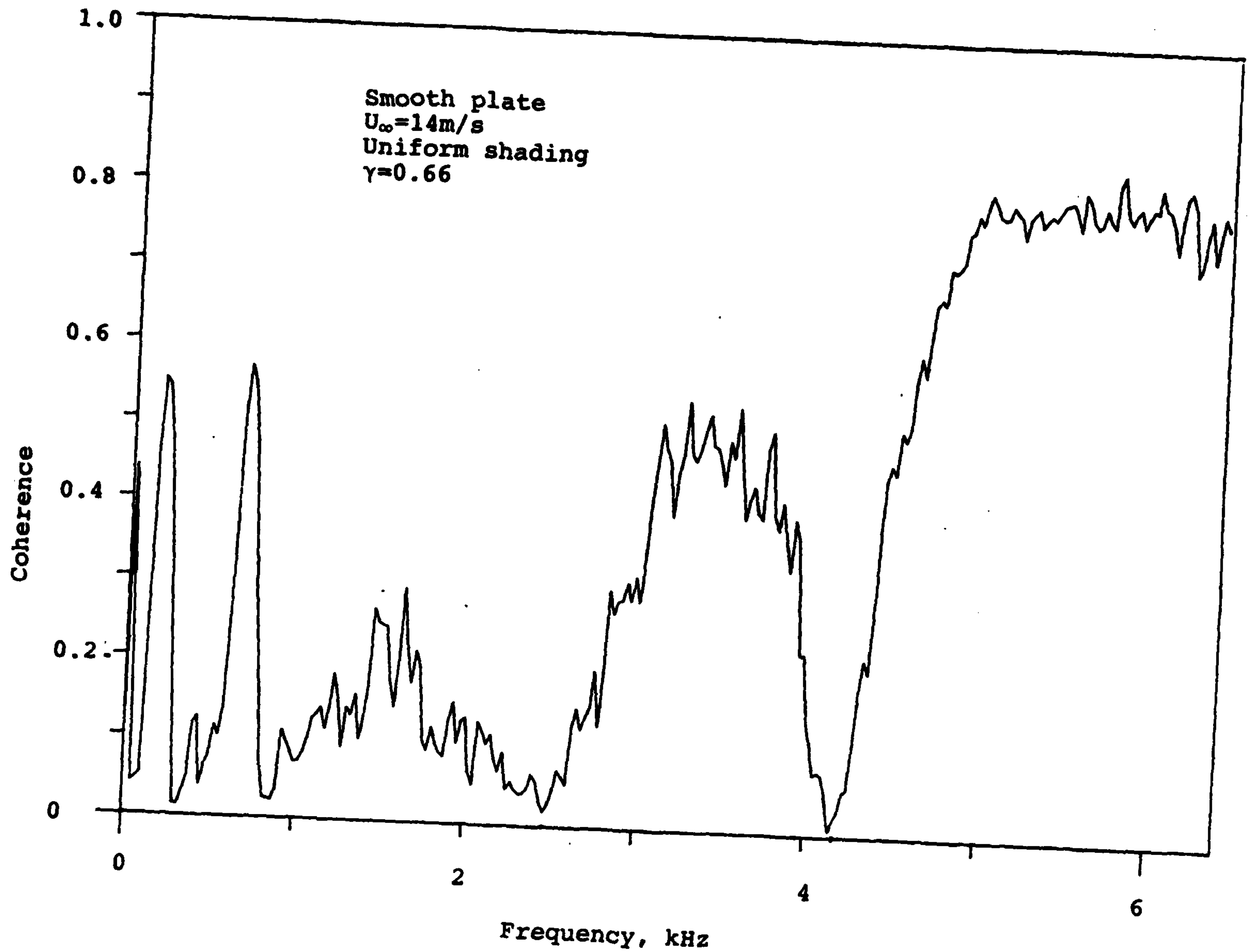

Figure 9. Typical Coherence Function for 3rd Microphone vs. Microphone Array.

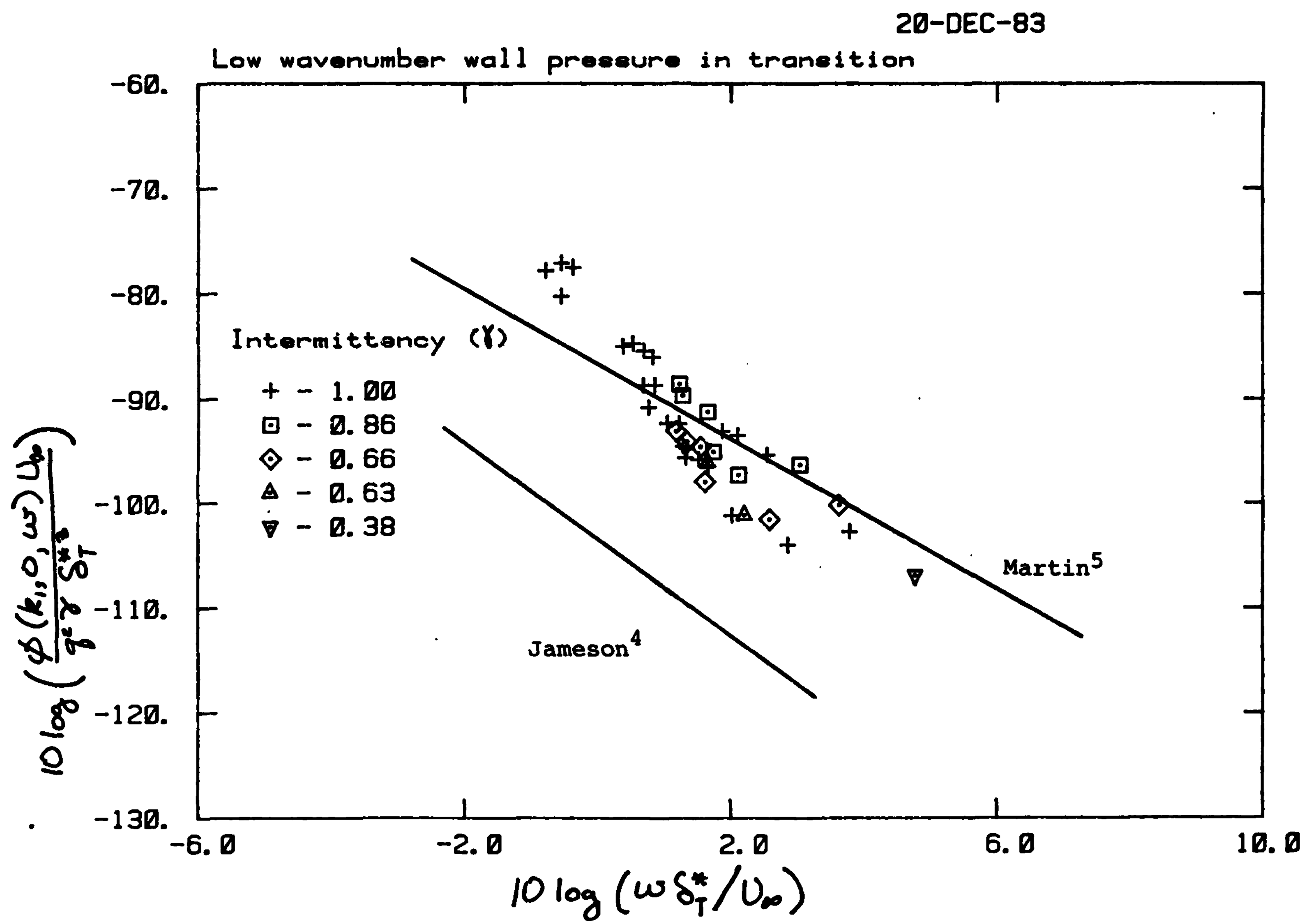

Figure 10. Low Wavenumber Wall Pressure Spectral Density in the Transition Region.

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